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HIGHWAY RESEARCH REPORT

ASPHALT DURABILITY TESTS AND THEIR RELATIONSHIP TO FIELD HARDENING

By
Glenn R. Kemp

Presented at the ASTM Symposium
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STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

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RESEARCH REPORT

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Mr. George B. Sherman is the principal investigator and Mr. Melvin H. Johnson and Mr. Glenn R. Kemp are the co-principal investigators of the research project where the information contained in this report was obtained.

Asphalt Durability Tests and Their Relationship to Field Hardening

By

Glenn R. Kemp

Abstract

A total of twenty-four asphalts in eight test sections are being evaluated relative to their change in viscosity with time. The test sections are located in different climatic areas in California. Statistical correlations are presented covering various laboratory test methods for predicting asphalt durability with 30 and 50 months of pavement service life. The laboratory test methods employed for predicting asphalt durability involve the concept whereby the asphalt is weathered by heat and air in a thin film. The amount of heat and thickness of the film varies, but the end result is basically volitization and/or oxidation to cause hardening of the asphalt. Additional correlations are presented using original voids and chemical procedures involving the Rostler analysis and Heithaus procedure. This report discusses the findings to date; and additional pavement service life will be required before final conclusions can be drawn.

Introduction

The Materials and Research Department of the California Division of Highways has since the 1930's engaged in studying asphalt durability. During that period many different approaches have been tried. Most of these methods have utilized a concept whereby the asphalt is weathered by heat and air in thin films. Chemical procedures using the Rostler analysis and Heithaus procedure have also been studied. The problem is concerned with the correlation of these laboratory test procedures with actual field weathering so that realistic specifications can be devised for controlling the field weathering qualities of an asphalt. In order for the laboratory tests to be of the greatest value they should correlate with field hardening even though climatic conditions may be quite different. This report gives statistical correlations of laboratory tests with field hardening of the asphalt in eight different field test sections located in different climatic areas in California.

Field Test Sections

In 1963 a new asphalt specification was proposed by the Materials and Research Department of the California Division of Highways which included requirements to control "setting" and durability.(1)

Table A shows this 1963 specification, also a revision made in 1965 to eliminate some repetitious tests and the present tentative specification which was revised in 1966 by altering the flash requirement.

Starting in 1964 with the Willits test section a series of test sections were placed in various climatic areas of the State. In these test sections, special asphalts, which were manufactured to meet the proposed tentative asphalt specifications, were placed and evaluated, along with a selected portion of the job asphalt as a control. The test sections were located, besides the Willits[2] location, at or near Folsom,[3] Benicia,[4] Martinez,[5] Los Altos,[6] Ludlow,[7] Olivehurst,[8] and Blythe,[9] California. Table B gives pertinent information as to contract road designation, date of placement, percent of asphalt used, type of climate, asphalt identification, and structural section. In each case the special asphalts were used in the same manner as the control or job asphalt. Figure 12 shows the geographical location of each test section.

The tentative specification based on viscosity grading after the Rolling Thin Film Test was designed, in addition to providing uniformity, to control "setting" and asphalt durability. Skog[10] in his study of setting and durability showed a good correlation between viscosity results on residues from AASHO Thin Film procedure and Rolling Thin Film Oven procedure. Skog and Sherman[11] later showed that the Rolling Thin Film residue viscosities correlate well with viscosities on recovered asphalt from original field mixes. Table C shows the viscosities of the Rolling Thin Film residues of the asphalts used in the test sections and how they compare with the viscosities of the recovered asphalts from the original mixes used in the test sections. No serious problems concerning "setting" occurred in the placement of the test sections as reported (2, 3, 4, 5, 6, 7, 8, 9), and the test requirements (Table A) indicate that the tentative specification asphalts being studied for durability in the test sections possessed adequate setting properties.

Laboratory Test Procedures

In early research on asphalt durability, the California Division of Highways developed the California Infrared Weathering Machine, which is described as to its design and operation in a paper entitled "The Operation Control and Application of the Infrared Weathering Machine - California Design."[12]

Subsequent investigations utilized other procedures, some of which employed a direct chemical analysis. The procedures which have been employed in the investigations involved in this report are described as follows:

a. <u>Ottawa Sand Mix - 140F (60C) - 400 hrs., 1000 hrs.</u>

This procedure, which is described under the title of California Infrared Weathering procedure, uses a mixture of Ottawa sand and 2 percent asphalt which is mixed for 3 minutes in a specially designed mixer at 325F (163C). The resulting mixture, which has been ascertained to have asphalt films on the aggregate of approximately 5 to 7 microns, is weathered in an uncompacted state in small lids in an oven heated by infrared lights shining on the asphalt mixture so that a surface and interior temperature of the mix is kept at 140F (60C) while air heated to 105F (41C) is blown across the surface of the asphalt mix.

b. <u>Weathering Plates - 210F (99C) - 24 hrs.</u>

This procedure described in Test Method No. Calif. 347 is a modification of the Shell Aging Index of Bituminous Materials test[13] and utilizes a 20 micron thick film of asphalt on a 50 mm square pyrex glass plate which is weathered in an oven for 24 hours at 210F (99C).

c. <u>Extended RTF - 325F (163C) - 5 hrs.</u>

This procedure is performed the same as the Method of Test for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test) ASTM D2872-70 except that the heating period is five hours plus 15 minutes warmup.[14] The asphalt is exposed to a temperature of 325F (163C) in a changing thin film with a jet of heated air injected into the bottle for approximately one second 15 times per minute.

d. <u>Field Density Briquette - 140F (60C) - 90 days</u>

This procedure utilizes briquettes 4 inches in diameter by approximately 2-1/2 inches high. These briquettes are prepared from the same aggregate as used in the field with the same gradation, the same asphalt type, percent asphalt, and mixed at the same temperature. Compaction of the briquette specimen is such that the percent voids are the same as the in-place field voids after construction. The prepared briquettes are then weathered in the California Infrared Weathering Oven at 140F (60C) and air blown across them at 105F (41C) for various periods of time. A testing period of ninety days was used in this study.

e. Rostler Ratio $\frac{N+A1}{P+A2}$

This ratio is derived from the Rostler Analysis[15] to define reactivity of the malthene fraction and is determined by dividing the sum of the two most reactive components of the malthene fraction by the two least reactive components. The method may be outlined as follows: A one gram sample of the asphalt is dissolved in 50 ml. of normal pentane and the precipitated asphaltenes are removed. This fraction is labeled "A" by Dr. Rostler. The solution is then treated with eighty-five percent sulfuric acid which separates a fraction containing the most reactive portions of asphalt, and according to Rostler, contains all of the nitrogen bases of the asphalt. This fraction is called "N". Sulfuric acid of ninety-eight percent strength is then used to separate the next most reactive fraction called "first acidaffins" and labeled "A1". Next the solution is treated with fuming sulfuric acid containing 30% SO_3. This treatment produces a fraction next in rank of reactivity, named "second acidaffins" and labeled "A2". The remaining least reactive fraction, the paraffins, is called "P". These residual fractions are then used to calculate the Rostler Ratio.

f. Percent Original Voids

The percent voids was determined on the basis of a theoretical specific gravity determined on the fine aggregate, coarse aggregate, and the asphalt used in the original mix. A ratio of the specific gravity of field cores to the calculated theoretical specific gravity subtracted from 100 gives the percent voids. The significance of percent original voids to asphalt weathering has been documented by several researchers as this apparently indicates the susceptibility of a pavement to oxidation.

g. Heithaus Value "P"

The Heithaus test[16] provides a method for studying the internal phase relationship of an asphalt. The technique provides a measure of the peptizing power of the malthenes Po, and the peptizability of the asphaltenes Pa. When the two factors are combined the state of peptization "P" ($P = \frac{Po}{1-Pa}$) can be determined. The higher the value of "P", the more stable the internal phase of the asphalt system.

h. Chevron Research RMFC Procedure

This procedure which was developed by the Chevron Research Corporation utilizes the apparatus of the Rolling Thin Film test ASTM D2872-70 plus some additional apparatus. Essentially an approximately 20 micron film of asphalt is formed in a Rolling Thin Film bottle by dissolving a specified amount of asphalt in benzene, coating the inside of the bottle during the evaporation of the benzene by rotating the bottle in the RTF oven for a specified period with the power off till the benzene is evaporated. After complete evaporation, the bottle is stoppered except for a small capillary tube through the stopper and the weathering period is then conducted for 48 hours in the RTF oven at 210F (99C) at the specified 15 rpm with no air being used. The weathered residue is then removed and tested. The concept of the weathering is that there is hardening through oxidation but that the evaporation present is contained and resolvated into the system as is theorized to happen to the asphalt in the enclosed void spaces in the pavement.

Laboratory Test Results

All of the tables presenting the test results of the various laboratory procedures to predict asphalt durability are related to the various test sections in the field by name designation and road. The asphalts used in the various test sections are identified by code letters to indicate their refinery source.

Table D shows the microviscosity results of the recovered asphalts from the test sections for 30 and 50 months weathering periods, the Extended Rolling Thin Film procedure for five hours, the weathering plates 210F (99C) for 24 hours, 400 and 1000 hour weathering periods of Ottawa Sand Mix in the California Infrared Machine, and the weathering of briquettes fabricated to field density for 90 days in the California Infrared Machine. Also shown on this table are values of the Rostler ratio $(\frac{N+A1}{P+A2})$, the percent voids of original cores from the pavements, and the Heithaus procedure. The last column includes the results furnished by Chevron Research from their Rolling Microfilm method using a modified Rolling Thin Film oven.

Analysis of Test Section Data

It was planned to core and test the various test sections at regular intervals of about two years. As can be seen on Table E, which shows data from all the test sections for the different corings, the intervals between corings varied from about 15 to 30 months.

In the Willits Test Section the special asphalt was manufactured in a very small quantity and was made to conform to the 1963 Tentative Specifications. Three different "setting" grades were made although their essential properties were the same. Figure 1 shows how the three special asphalts and the control asphalt compare to each other after 62 months of field weathering. The special asphalts used in this test section show superior durability properties. In this section the control asphalt although not as good as the special asphalts is still excellent in its weathering properties. Undoubtedly the very low voids is a significant factor in the superior performances by all of the asphalts in the Willits Test Section.

The special asphalt used in the Folsom, Benicia, Martinez and Los Altos test sections come from one refinery. All of these sections were laid within 18 months of each other as can be seen on Table B. Figures 2, 3, 4, and 5 show how the special asphalts compared to the control asphalts. As can be seen in Figure 6 which compares the special asphalt from the different sections, they are each weathering similarly except for the Martinez test section which had the largest percentage of initial voids.

In the Ludlow test section, as shown on Figure 7, special asphalts designed to meet the Asphalt Institute AC-12 grading were placed in comparison to special asphalts meeting the 1966 California tentative specification. In addition to the regular 85-100 contract control asphalt another source of 85-100 asphalt meeting the standard specifications was placed as an additional test section. As seen on Figure 7, the various asphalts are weathering individually somewhat different but the whole group of asphalts show that the conditions evident in this test section are affecting the group similarly.

In the Olivehurst and Blythe test sections, two additional sources of special tentative specification asphalt were employed. The Olivehurst section compares two sources of tentative specification asphalt, one of which is the same as used in the Ludlow test section, while the special asphalt in the Blythe test section is represented by yet another source. Figures 8 and 9 show how the different asphalts compare with each other in the Olivehurst and Blythe test sections. The data for these three sections is not as conclusive, as the weathering period has only been about 30 months. This is very evident in the Blythe test section as shown on Figure 9 by the wide separation between the weathering curves. Partly this can be attributed to the control asphalt being a 200-300 material but the special 85-100 control asphalt is just as different from the tentative specification asphalt as the 200-300 asphalt. Further weathering in this area hopefully will tell what the weathering picture really will be.

An analysis of all of the test sections shows that in each test section the control asphalt is weathering at about the same rate as the special asphalt. Exceptions are the Willits and Blythe test sections where the control 85-100 paving asphalts are weathering at a faster rate. Another slight exception is the special AC-12 asphalt "E" in the Ludlow test section which exhibits much better ductile properties than the other asphalts in this test section although its viscosity results do not indicate a much different weathering pattern. With all the asphalts, special and control, weathering at about the same rate in all the sections, there are some exceptions in which the rate of weathering is greatly accelerated. In the Martinez test section, which contains the same asphalts generally as the Folsom, Benicia and Los Altos test sections and similar climatic conditions, the weathering has been dramatically increased. The asphalts in the Martinez section have penetrations of 10 and 12 for the control and special asphalts, where in the other test sections the asphalts average 22 and 23 penetration respectively for the special and control asphalts for about the same weathering period.

Table F shows the results of visual observations for cracks and deflection measurements. In the Martinez section we see that the road has extensive block and chicken wire cracking in both the special and control sections. None of the other test sections exhibit any cracking at this time. In all of the test sections, the deflection values are low, even in the Martinez test section. This indicates that the structural sections were well designed as there is no instability although there is extensive bleeding in various portions of the control 200-300 asphalt of the Blythe test section. No bleeding is evident in the tentative specification asphalt section or the special 85-100 asphalt section even though they used the same mix design and asphalt content as the 200-300 asphalt. No bleeding is evident in any of the other test sections.

Correlation Laboratory and Field Test Results

The basic purpose of this research effort was to determine if laboratory test procedures can reliably predict field asphalt durability. Since change in consistency with aging is a recognized parameter of asphalt durability, the viscosities obtained from field samples after 30 and 50 months were correlated with the viscosity results of various laboratory aging tests. The values from the Rostler Ratio, Heithaus procedure and percent original voids, of course, were not in viscosity terms. In all instances the viscosity values are in megapoise and were determined with the sliding plate micro-viscometer at $.05 sec^{-1}$ shear rate.

The statistical methods selected to provide the most meaningful results was a very difficult job. The field data is from eight different test sections with different asphalts, asphalt contents, gradings, compaction, climatological conditions, etc. To rate all the different asphalts under identical conditions is not possible. This is not necessarily a bad situation in that asphalt specifications should be written with the intent that the asphalt will be used under a variety of conditions.

Two statistical programs were used in the correlation, with each having advantages and disadvantages.

a. Least Squares Regression Analysis

A linear transformation of the power function ($Y+AX^b$) and the exponential function ($Y=Ae^{bx}$) was utilized to determine the better regression. The power function was used when viscosities were plotted against viscosity and the exponential function was used when field viscosity was plotted against a linear number such as % voids, Rostler Ratio and Heithaus P. All the data were correlated on the basis that all test sections together represent a single test section. Table G lists the correlation coefficients and Standard Error of Estimate for the various test methods when comparing 30 and 50 months field weathering. Figure 10 presents a graphic comparison of the correlation coefficients.

b. Covariance Analysis

This analysis is outlined by W. J. Dixon and F. J. Massey, Jr. in their publication "Introduction to Statistical Analysis."[17] In this system the individual correlations of the test sections are compared based on a common slope. This analysis tends to negate individual difference of the separate test sections such as voids, asphalt content, geographical location, etc. The correlation coefficients are shown in Table H and graphically shown in Figure 11.

Both statistical programs were performed on data from all eight test sections at 30 months field service life and also on five test sections where the service life exceeded 50 months. The five test sections at 50 months were also analyzed at 30 months for comparison.

In comparing the correlation coefficients by the different statistical methods we see that none of the correlation values will sufficiently indicate that any of the laboratory test procedures could be depended upon to adequately predict field weathering durability. One possible exception is the correlation between the Chevron RMFC vs. the field data for eight test sections at 30 months by covariance analysis. In regard to the correlation coefficients determined on the 50 months data we see the best correlation is by the percent original voids no matter what statistical program is used. Therefore, to adequately measure the efficiency of the test methods a field comparison under relatively uniform void conditions is desirable.

In analyzing the two statistical programs we see that the least squares regression analysis is encompassing all effects including test section variables such as grading, aggregates, voids, climatic condition, etc. The covariance analysis program offers a way to eliminate effect of test sections and is probably the best program except each test section should contain sufficient test asphalts to produce a reliable correlation within each test section. In this study four of the five oldest test sections contain only two asphalts which makes the covariance analysis questionable.

Findings To Date

1. All of the tentative specification asphalts graded on the basis of RTFO residue viscosity had excellent "setting" properties regardless of supplier.

2. The superior qualities of the experimental asphalts used in the Willits test section appear to be a combination of moderately low voids and good asphalt durability properties.

3. In most of the test sections it appears that the special asphalts did not weather significantly different than the control asphalts and that the test section conditions also dictated the weathering rates of the asphalts involved.

4. The original void content of the pavement appears to be a definite factor in long term asphalt durability. The evidence was most indicative at the 50 months weathering correlation.

5. All of the test sections were in good physical condition at 30+ months except for the Martinez test section which is exhibiting extensive block cracking in both the special and control asphalt areas and the control 200-300 asphalt portion of the Blythe project which is exhibiting "bleeding".

6. The poorest correlation with field weathering, in general, was obtained with the weathering plate test 210F (99C) used in the tentative specification. The best correlation appears to be with the Chevron RMFC test at 48 hours.

Conclusions

1. Grading asphalt on the basis of viscosity at 140F (60C) after a treatment test that simulates field mixing (Rolling Thin Film Test or Thin Film Test) will produce mixes that have better uniformity relative to "setting" during rolling. This uniformity was consistent regardless of manufacturer.

2. Initial pavement air voids is an important factor in controlling early asphalt hardening. Pavement air voids should be as low as possible without sacrificing stability or cause pavement "bleeding".

3. More field weathering time is needed before final conclusions can be made on the reliability of the various laboratory test methods for predicting asphalt durability.

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TABLE A

CALIFORNIA TENTATIVE ASPHALT SPECIFICATIONS

Test	Method	Proposed 1963	Modified 1965	Modified 1966
FLASH POINT, P.M.C.T. °F MIN.	AASHO T-73	475	475	450
PENETRATION OF ORIGINAL SAMPLE AT 77°F	AASHO T-49	85-100	-	-
STAIN NUMBER OF ORIGINAL SAMPLE MAX. AFTER 120 HRS.-140°F-50#/SQ.IN.	ASTM D-1328	10	10	10
VISCOSITY, on original sample	AASHO			
140°F, MINIMUM, poise	T-202	2200	-	-
225°F, MINIMUM, cSt	T-201	1800	-	-
325°F, MAXIMUM, cSt	T-201	200	-	-
COHESIOGRAPH READING-ORIG. MIN. IN.	Calif.	0.80	-	-
GAIN 0-24 HRS. MIN. IN.	No. 350	0.08	-	-
ROLLING THIN FILM TEST 325°F, 75 MIN.	Calif. No. 346			
PEN. RESIDUE, 77°F, MIN.	AASHO T-49	55	-	-
DUCT. RESIDUE, 77°F, MIN., cm	AASHO T-51	75	75	75
VISCOSITY				
140°F, POISES	AASHO T-202		4,000-6,000	4,000-6,000
275°F, CENTISTOKES	AASHO T-201		425-800	425-800
DURABILITY TEST	Calif. No. 347			
VISCOSITY OF RESIDUE AFTER DURABILITY TEST, MEGAPOISES AT 77°F	Calif. No. 348			
SHEAR RATE 0.05 $SEC.^{-1}$ MAX.		20	25	25
SHEAR RATE 0.001 $SEC.^{-1}$ MAX.		60	60	60
MICRO DUCTILITY OF RESIDUE 1/2 CM/MIN. MINIMUM, mm	Calif. No. 349	10	10	10
SOLUBILITY, CCL_4, ORIG. SAMPLE, % MIN.	AASHO T-44	99	99	99
ROLLING THIN FILM TEST, 375°F -75 MIN.	Calif. No. 346			
PEN. RESIDUE 77°F, MIN.	AASHO T-49	45	-	-
DUCT. RESIDUE 77°F, MIN., cm	AASHO T-51	60	-	-

TABLE B

DURABILITY TEST SECTIONS

Location Contract Road	Date Placed % Asphalt	Climatic Area	Asphalts Type *	 (ID)	Structural Section Thickness and Type Seal	 Surf. (Special)	 Base (Type)
Willits 64-1T13C4-P	Aug. 1964 (5.6%)	Coastal Valley Hot-Summ. Wet-Wint.	S 5.5 S 4.5 S 3.5 C85-100	(D) " " (G)	Fog	0.33' AC (0.17' AC)	0.33' (A) PMCTB 0.33' (B) PMCTB
Folsom 65-3T13C- 074024 03-Sac,ED-50	Aug. 1965 (5.5%)	Central Valley Hot-Summ. Wet-Wint.	S-Tent. Spec. C85-100	(D) (C)	0.05' OG AC	0.33' AC (0.17' AC)	0.25' ACB 0.50' AB 1.0' AS
Benicia 65-10MAC- 049004 10-Sol-21,680	Oct. 1965 (6.5%)	Coastal Bay Area Warm-Summ. Wet-Wint.	S-Tent. Spec. C85-100	(D) (B)	0.06' OG AC	0.17' AC (A) 0.33' AC (B) (0.17'AC"A")	0.67' AB 0.92' AS
Martinez 04-120224 04-CC-4-4.4/ 9.8	Sept.1966 (5.0%)	Coastal Bay Area Warm-Summ. Wet-Wint.	S-Tent. Spec. C85-100	(D) (B)	None	0.33' AC (0.17' AC)	0.25' ACB 0.67' AB 1.5' AS
Los Altos 04-170374 04-SCl-280- 11.5/18.9	Dec. 1966 (5.5%)	Coastal Bay Area Warm-Sum. Wet-Wint.	S-Tent. Spec. C85-100	(D) (D)	None	0.50' AC (0.17' AC)	0.42' (A) PMCTB 0.42' (B) PMCTB
Ludlow 08-039334 08-SBd-40- R28.4/R42.1	June 1967 (4 Asph.) Jul,Aug.'67 (Spec.T.S.) (5.3%)	High Desert Hot-Sum. Cool-Wint.	S-AC12 S-AC12 85-100 C85-100 S-Tent. Spec. S-Tent. LV Spec.	(E) (A) (A) (F) (A) (A)	0.04' OG AC	0.35' AC (0.17' AC) (S-Tent.Spec. 0.35' AC)	0.50' (B) PMCTB 0.80' AS
Olivehurst 03-020964 03-Yub-70- 0.1/R8.9	Sept.1967 (5.4%)	Central Valley Hot-Sum. Wet-Wint.	S-Tent. Spec. S-Tent. Spec. C85-100	(C) (A) (C)	None	0.33' AC (0.17' AC)	0.67' AB 1.0' AS
Blythe 11-037564 11-Riv-10- R133.5/	Oct. 1968 (C200-300) Nov-Dec'68 (Spec.T.S.) Jan-Feb'69 (85-100) (4.1% base) (4.5% surf)	Low Desert Very Hot Summers Warm-Wint.	C-200/ 300 S-Tent. Spec. 85-100	(H) (H) (M)	0.05' OG AC	0.30' AC (0.30' AC surf. & 0.25' AC base) (85-100 - 0.30' surf.)	0.25' AC 0.60' AB

*S = Special
C = Control

TABLE C

ASPHALT DURABILITY TEST SECTIONS

Comparison of Viscosities of Asphalts Recovered from Original Mixes and Residue from Rolling Thin Film Oven Test

Test Section Road	Asphalt Grade (Source)	Original Mix Asphalt		Rolling Thin Film Residue	
		Vac. Cap. Vis. 140°F (Poise)	Kin. Vis. 275°F (cSt)	Vac. Cap. Vis. 140°F (Poise)	Kin. Vis. 275°F (cSt)
Folsom 03-Sac, ED-50	S-Tent. Spec. (D)	4319	496	4060	467
	C-85/100 (C)	4568	510	3829	466
Benicia 10-SOL-21,680	S-Tent. Spec. (D)	5005	541	5035	521
	C-85/100 (B)	5911	679	7005	705
Martinez 04-CC-4-4.4/9.8	S-Tent. Spec. (D)	4184	470	3878	465
	C-85/100 (B)	2462	363	2257	330
Los Altos 04-SCl-280 11.5/18.9	S-Tent. Spec. (D)	3426	522	3930	454
	C-85/100 (D)	2957	467	3268	425
Ludlow 08-SBd-40-R28.4/ R42.1	S-AC12 (E)	2014	254	1808	244
	S-AC12 (A)	3732	507	2884	447
	85/100 (A)	4909	534	3955	516
	C-85/100 (F)	2914	291	2397	261
	S-Tent. Spec. (A)	5165	578	4346	528
	S-Tent. (A) Spec. L.V.	3136	457	2634	418
Olive-hurst 03-Yub-70-0.1/R8.9	S-Tent. Spec. (C)	6063	562	4316	465
	S-Tent. Spec. (A)	6080	614	4487	531
	(85-100 (C)	7901	675	4603	537

TABLE D

ASPHALT DURABILITY TEST SECTIONS

30 & 50 Month Field Weathering and Various Laboratory Procedures Viscosity Test Data (Surface Course-Microvis. at 77°F-0.05s^{-1}S.R.- all test results Megapoise except Rostler Ratio, % Voids, & Heithaus "P")

Test Section Road	Asphalt Type* (Source Grade	Field Results 30 mo	Field Results 50 mo	Various Laboratory Procedures Test Results: Ext. RTF 5hr	WP 210F 24hr	OSM 140F 400hr	OSM 140F 1000hr	F.D. Briq. 90day	Rostler $\frac{N+A_1}{P+A_2}$	% Orig. Voids	Heit-haus "P"	Chevron RMFC
Willits 01-Men	S(D)5.5	5.3	6.1	15	13	13	20		1.25	5.2	6.0	18
	S(D)4.5	4.2	5.0	14	13	11	18		.95	5.1	6.3	13
	S(D)3.5	3.6	5.2	12	12	9	15		1.22	6.7	6.0	10
	C(G)85-100	7.9	9.8	24	29	44	110		1.85	6.5	3.3	36
Folsom 03-Sac, ED-50	S(D)TS	23	25	21	26	37	108		1.98	7.0	3.5	29
	C(C)85-100	17	21	26	45	23	52		1.24	7.8	3.3	21
Benicia 10-Sol-21	S(D)TS	27	34	23	16	32	103	28	1.78	8.2	3.5	45
	C(B)85-100	20	22	32	91	50	192	31	1.90	8.3	3.9	44
Martinez 04-CC-4	S(D)TS	72	197	22	29	43	100		1.83	10.3	3.5	37
	C(B)85-100	59	224	21	41	24	71		1.63	8.7	4.2	45
LosAltos 04-SCl-280	S(D)TS	25	29	23	33	32	80		1.80	6.4	3.6	35
	C(D)85-100	25	29	26	83	22	89		1.70	4.8	4.1	41
Ludlow 08-SBd-40	S(E)AC12	22		13	12	11	28	17	1.50	4.0	5.8	9
	S(A)AC12	36		25	27	27	100	26	1.70	5.1	3.8	23
	(A)85-100	52		27	31	39	105	28	1.80	6.4	3.5	30
	C(F)85-100	50		27	74	27	80	35	1.59	5.4	3.8	40
	S(A)TS	36		30	25	52	135	30	1.50	6.8	3.6	39
	S(A)L.V. TS	24		16	17	26	74	19	1.40	5.8	3.6	20
Olive-hurst 03-Yub-70	S(C)TS	27		27	34	32	76	31	1.37	7.0	3.4	28
	S(A)TS	26		28	24	50	125	35	1.47	6.6	3.5	27
	C(C)85-100	25		25	34	28	78	31	1.22	9.8	3.5	35
Blythe 11-Riv-10	S(H)TS	36		28	31	17	44		1.45	7.2	4.3	27
	C(H)200-300	5.4		2.5	6	3.8	12		1.50	4.4	4.4	2
	C(M)85-100	135		28	44	48	132			6.9		

*S = Special Asphalts
C = Control Asphalts
TS = Calif. Tentative Specification (4000-6000 poise at 140°F after RTF)

TABLE E

ASPHALT DURABILITY TEST SECTIONS

Recovered Asphalt Test Results (Surface Course)

Test Section Road	Asphalt (Source)	Grade	Pvt. Age (mo)	Tests: Pen. 77°F	S.P. °F	Duct. 77°F (cm)	Micro-viscosity Megapoise $.05s^{-1}SR$	Micro-viscosity Megapoise $.001s^{-1}SR$	Shear Susp.	Micro-Duct. (mm)
Willits 01-Men-101	Special (D)	5.5 VFSet	0				2.82	5.53	.18	31
			22				4.93	11.0	.18	22
			62				6.59	17.6	.23	17
		4.5 FSet	0				2.62	4.42	.13	35
			22				3.83	7.1	.16	27
			62				5.67	14.3	.21	21
		3.5 MSet	0				2.05	3.88	.16	37
			22				3.2	7.7	.22	24
			62				6.43	17.0	.21	20
	Control (G)	85-100	0				3.57	5.12	.09	57
			22				7.23	9.8	.09	46
			62				11.2	20.8	.11	36
Folsom 03-Sac, ED-50	Special (D)	Calif. Tent. Spec.	0	54	126	100+	4.22	6.38	.11	63
			29	25	137	100+	22.8	32.6	.08	36
			52	23	140	100+	24.7	40.9	.12	31
	Control (C)	85-100	0	54	124	100+	3.4	4.8	.09	56
			29	29	135	100+	16.8	32.2	.15	27
			52	24	140	95	20.9	44.1	.18	16
Benicia 10-Sol-21,680	Special (D)	Calif. Tent. Spec.	0	50	127	100+	4.9	6.6	.08	69
			30	23	145	87	27.3	46.7	.13	18
			57	21	148	100+	35.5	73.8	.19	9
	Control (B)	85-100	0	53	128	100+	4.6	7.3	.12	53
			30	26	142	94	20.3	39.7	.17	14
			57	24	146	100+	22.4	49.8	.19	16
Martinez 04-CC-4-4.4/9.8	Special (D)	Calif. Tent. Spec.	0	53	126	100+	6.2	7.6	.06	71
			22	25	142	100+	30.9	54.6	.15	5
			48	12	153	16	197.0	531.0	.22	2
	Control (B)	85-100	0	54	122	100+	4.4	5.1	.04	72
			22	26	136	100+	23.3	30.4	.06	65
			48	10	150	60	224.0	416.0	.15	5
Los Altos 04-SCl-280-11.5/	Special (D)	Calif. Tent. Spec.	0	54	124	100+	2.34	3.73	.12	65
			19	26	137	100+	19.6	30.7	.11	34
			45	22	141	100+	28.4	55.5	.17	14
	Control (D)	85-100	0	54	122	100+	2.19	2.64	.05	61
			19	27	135	100+	16.9	22.6	.08	41
			45	21	139	100+	27.7	50.3	.15	26

TABLE E (Con't)

ASPHALT DURABILITY TEST SECTIONS

Recovered Asphalt Test Results (Surface Course)

Test Section Road	Asphalt (Source)	Grade	Pvt. Age (mo)	Tests: Pen. 77°F	S.P. °F	Duct. 77°F (cm)	Micro-viscosity Megapoise .05s^{-1}SR	Micro-viscosity Megapoise .001s^{-1}SR	Shear Susp.	Micro-Duct. (mm)
Ludlow 08-SBd-40-R28.4/R42.1	Special (E)	AC-12	0	59	114	100+	2.21	2.32	.01	92
			20	25	131	100+	15.5	15.5	.00	127
			40	21	136	150+	28.0	34.7	.05	53
	Special (A)	AC-12	0	68	122	100+	2.62	3.86	.10	58
			20	23	147	62	26.1	72.0	.26	7
			40	15	148	67	44.7	130.0	.28	5
	Std.Spec. (A)	85-100	0	47	128	100+	4.29	5.28	.06	71
			20	18	146	22	41.0	98.8	.20	12
			40	18	149	22	59.8	156.0	.23	7
	Control (F)	85-100	0	50	126	100+	3.50	3.95	.03	89
			21	18	142	78	35.8	71.2	.18	19
			40	15	150	61	65.2	159.0	.24	4
	Special (A)	Calif. Tent. Spec.	0	50	126	100+	4.59	5.75	.06	65
			19	22	144	73	25.9	61.2	.21	10
			38	19	149	20	40.7	106.0	.25	5
	Special (A) (LowVis)	Calif. Tent. Spec.	0	66	120	100+	2.32	3.15	.08	57
			18	31	136	100+	14.5	23.6	.12	19
			38	23	146	58	31.2	82.5	.23	7
Olivehurst 03-Yub-70,65	Special (C)	Calif. Tent. Spec.	0	41	127	100+	6.6	8.7	.07	75
			15	29	135	100+	15.7	21.7	.13	43
			33	23	145	68	30.0	87.8	.24	8
	Special (A)	Calif. Tent. Spec.	0	45	129	100+	5.7	7.4	.07	57
			15	30	137	100+	15.1	28.1	.15	22
			33	23	144	61	29.7	74.5	.23	6
	Control (C)	Calif. Tent. Spec.	0	45	130	100+	6.6	10.1	.11	39
			15	31	143	51	23.6	80.0	.31	7
			33	25	145	45	24.8	70.7	.26	7
Blythe 11-Riv-R133.5/R149.5	Special (H)	Calif. Tent. Spec.	6	40	126	100+	6.1	7.72	.06	76
			24	20	144	103	29.2	76.2	.25	11
	Control (H)	200/300	8	63	117	100+	1.74	1.93	.03	71
			25	44	125	150+	4.78	6.1	.05	70
	Std.Spec. (M)	85-100	4	29	136	100+	11.6	11.6	.00	91
			22	11	150	23	102.0	205.0	.18	2

TABLE F

ASPHALT DURABILITY TEST SECTIONS
DEFLECTION & VISUAL INSPECTION DATA

Test Section Road	Asphalt (Source)	Grade	Deflection Data: Wheel Track IWT	OWT	Latest Date	Visual Inspection Data: Cracks, etc.	Latest Date
Willits 01-Men-101	Spec.(D)	5.5VFS	.006"	.005"	4-69	Some Reflection	7-71
	Spec.(D)	4.5FS	.007"	.007"	"	" Cracking	"
	Spec.(D)	3.5MS	.008"	.006"	"	"	"
	Cont.(G)	85-100	.008"	.006"	"	"	"
Folsom 03-Sac,ED-50	Spec.(D)	TenSpec	.005"	.004"	4-71	No Cracking	5-71
	Cont.(C)	85-100	.004"	.004"	"	" "	"
Benicia 10-Sol-21,680	Spec.(D)	TenSpec	.013"	.013"	2-71	No Cracking	3-71
	Cont.(B)	85-100	.011"	.011"	"	" "	"
Martinez 04-CC-4	Spec.(D)	TenSpec	.013"	.012"	4-71	Block & Alligator Cracking both Asph.	3-71
	Cont.(B)	85-100	.012"	.011"	"		"
Los Altos 04-SCl-280	Spec.(D)	TenSpec	.001"	.001"	3-71	No Cracking	5-71
	Cont.(D)	85-100	.001"	.001"	"	" "	"
Ludlow 08-SBd-40	Spec.(E)	AC-12	.003"	.003"	3-69	No Cracking	1-71
	Spec.(A)	AC-12	.0014"	.0013"	"	" "	"
	(A)	85-100	.0014"	.0013"	"	" "	"
	Cont.(F)	85-100	.0014"	.0013"	"	" "	"
	Spec.(A)	TenSpec	.001"	.0005"	"	" "	"
	Sp.LV(A)	TenSpec	.0015"	.0017"	"	" "	"
Olivehurst 03-Yub-70	Spec.(C)	TenSpec	-	.012"	3-70	No Cracking	5-71
	Spec.(A)	TenSpec	-	.020"	"	" "	"
	Cont.(C)	85-100	-	.019"	"	" "	"
Blythe 11-Riv-10	Spec.(H)	TenSpec	-	-	-	No Cracking	1-71
	Cont.(H)	200-300	-	-	-	" " (Ext.Bleeding)	"
	(M)	85-100	-	-	-	" "	"

TABLE G

Correlation Coefficients (Least Square Regression Analysis) of Field Viscosities at 30 & 50 Months vs. Various Laboratory Procedures Test Data

Test Method Designation	Field Weathering Period	No. of Test Sections	Correlation Coefficient	Standard Error of Estimate	
				Laboratory	Field
Field Density Briq. 90 days	30 Months	3	.34	5.8	11.0
Percent Original Voids		8	.39	1.52	28.6
Rostler Ratio $N+A_1/P+A_2$		"	.51	.23	18.0
Wea. Plates-210°F-24 hours		"	.58	21.7	28.9
Ext. RTF-325°F-5 hours		"	.59	6.3	27.5
Chevron RMFC-48 hours		"	.64	10.5	15.8
Heithaus "P"		"	.65	.75	17.4
O.S.M. 140°F-400 hours		"	.65	12.9	26.3
O.S.M. 140°F-1000 hours		"	.72	43.8	26.6
Wea. Plates-210°F-24 hours	30 Months	5	.57	27.0	23.8
Ext. RTF-325°F-5 hours		"	.66	5.1	23.7
Rostler Ratio $N+A_1/P+A_2$		"	.67	.26	21.4
Percent Original Voids		"	.69	1.25	12.8
O.S.M. 140°F-400 hours		"	.71	12.8	21.4
O.S.M. 140°F-1000 hours		"	.73	53.8	22.0
Heithaus "P"		"	.73	.82	21.4
Chevron RMFC-48 hours		"	.81	9.7	18.5
Wea. Plates-210°F-24 hours	50 Months	5	.46	28.2	84.0
Ext. RTF-325°F-5 hours		"	.50	5.6	84.7
Rostler Ratio $N+A_1/P+A_2$		"	.55	.29	82.0
O.S.M. 140°F-400 hours		"	.57	14.1	81.9
O.S.M. 140°F-1000 hours		"	.59	58.6	82.5
Heithaus "P"		"	.60	.96	81.9
Chevron RMFC-48 hours		"	.72	11.4	75.6
Percent Original Voids		"	.74	1.15	57.2

Note: $Y=Ae^{bx}$ used for Heithaus P, Percent Voids and Rostler Ratio
$Y=AX^b$ used in all other correlations.

TABLE H

Correlation Coefficients (Linear Covariance Analysis) of Field Viscosities at 30 & 50 Months vs. Various Laboratory Procedures Test Data

Test Method Designation	Field Weathering Period	No of Test Sections	Correlation Coefficient
Wea. Plates-210°F-24 hours	30 Months	8	No Analysis
Percent Original Voids		"	.39
Rostler Ratio $N+A_1/P+A_2$		"	.51
Ext. RTF-325°F-5 hours		"	.59
Herthaus "P"		"	.64
O.S.M. 140°F-400 hours		"	.67
O.S.M. 140°F-1000 hours		"	.72
Field Density Briq. 90 days		3	.83
Chevron RMFC-48 hours		8	.93
Chevron RMFC-48 hours	30 Months	5	No Analysis
Wea. Plates-210°F-24 hours		"	.56
Ext. RTF-325°F-5 hours		"	.66
Rostler Ratio $N+A_1/P+A_2$		"	.67
Percent Original Voids		"	.68
O.S.M. 140°F-400 hours		"	.71
O.S.M. 140°F-1000 hours		"	.73
Heithaus "P"		"	.73
Wea. Plates-210°F-24 hours	50 Months	5	No Analysis
Ext. RTF-325°F-5 hours		"	.50
Rostler Ratio $N+A_1/P+A_2$		"	.55
O.S.M. 140°F-400 hours		"	.57
O.S.M. 140°F-1000 hours		"	.59
Heithaus "P"		"	.60
Chevron RMFC-48 hours		"	.72
Percent Original Voids		"	.74

Figure 1

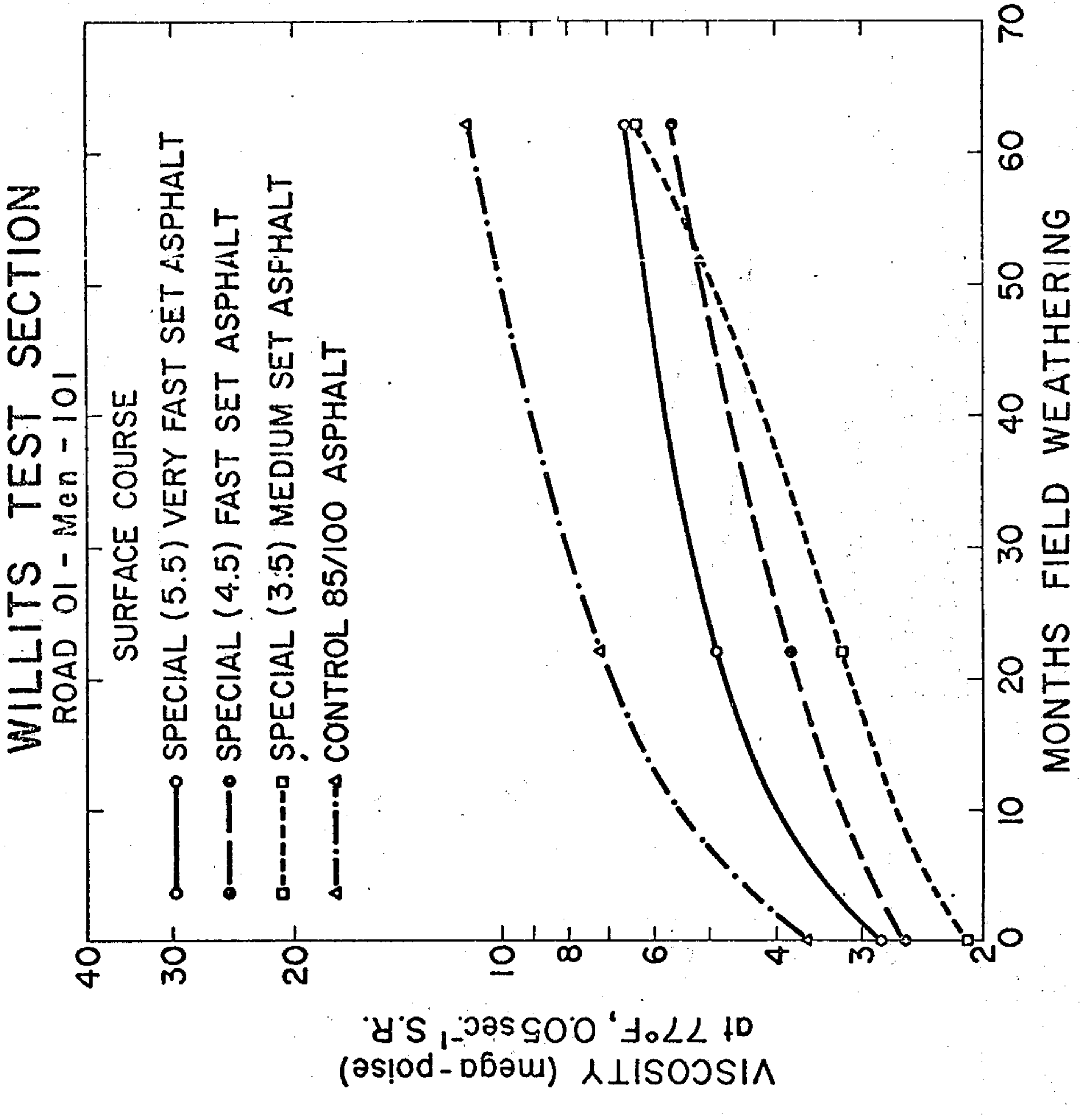
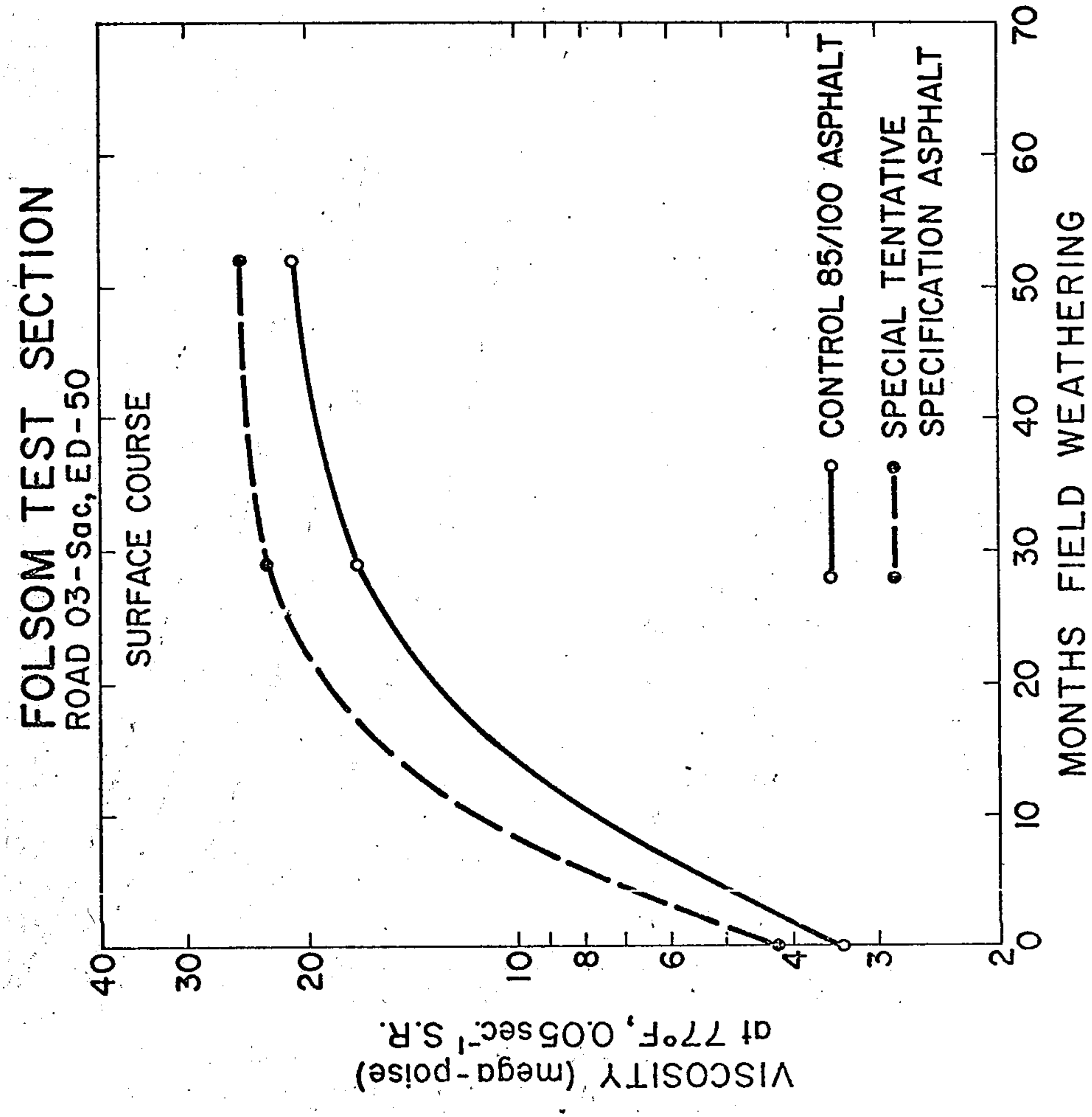
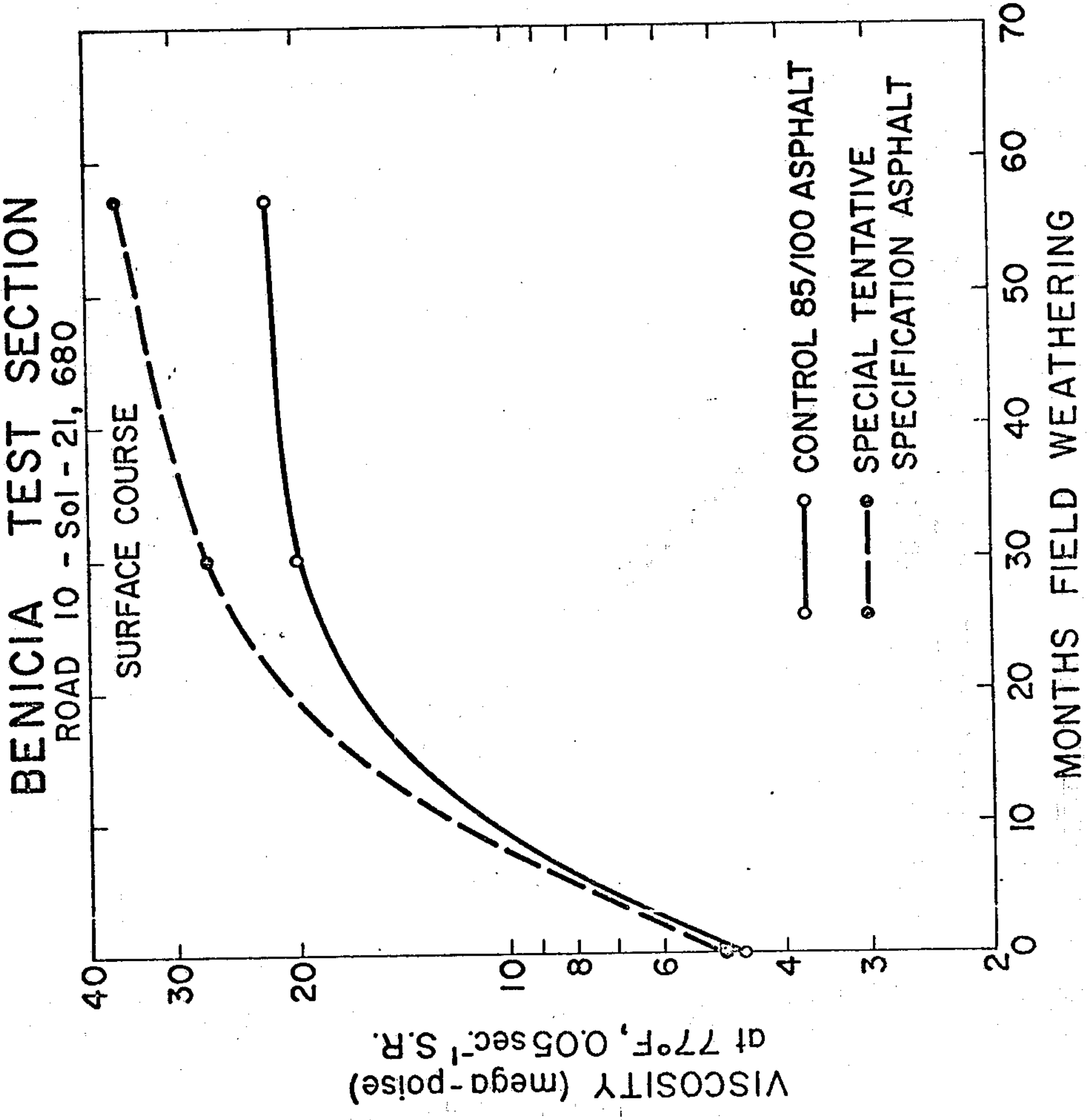

WILLITS TEST SECTION
ROAD 01 - Men - 101
SURFACE COURSE
SPECIAL (5.5) VERY FAST SET ASPHALT
SPECIAL (4.5) FAST SET ASPHALT
SPECIAL (3.5) MEDIUM SET ASPHALT
CONTROL 85/100 ASPHALT
VISCOSITY (mega-poise)
at 77°F, 0.05 sec.⁻¹ S.R.
MONTHS FIELD WEATHERING
40
30
20
10
8
6
4
3
2
0
10
20
30
40
50
60
70

Figure 2



FOLSOM TEST SECTION
ROAD 03-Sac, ED-50
SURFACE COURSE
CONTROL 85/100 ASPHALT
SPECIAL TENTATIVE
SPECIFICATION ASPHALT
MONTHS FIELD WEATHERING
VISCOSITY (mega-poise)
at 77°F, 0.05 sec⁻¹ S.R.
0
10
20
30
40
50
60
70
2
3
4
6
8
10
20
30
40

Figure 3



BENICIA TEST SECTION
ROAD 10 - Sol - 21, 680
SURFACE COURSE
CONTROL 85/100 ASPHALT
SPECIAL TENTATIVE SPECIFICATION ASPHALT
VISCOSITY (mega-poise) at 77°F, 0.05 sec.⁻¹ S.R.
MONTHS FIELD WEATHERING
0
10
20
30
40
50
60
70
2
3
4
6
8
10
20
30
40

Figure 4

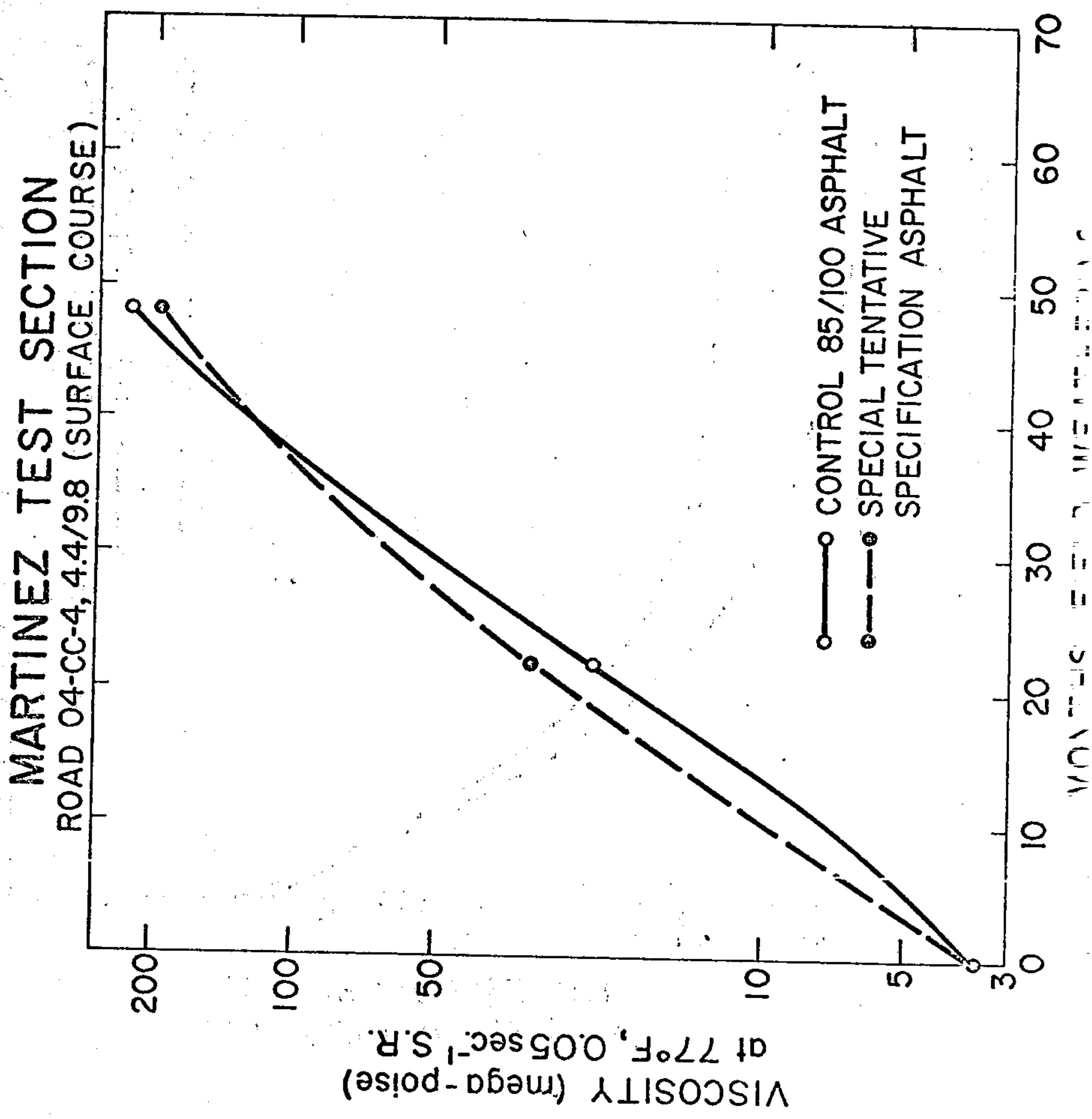
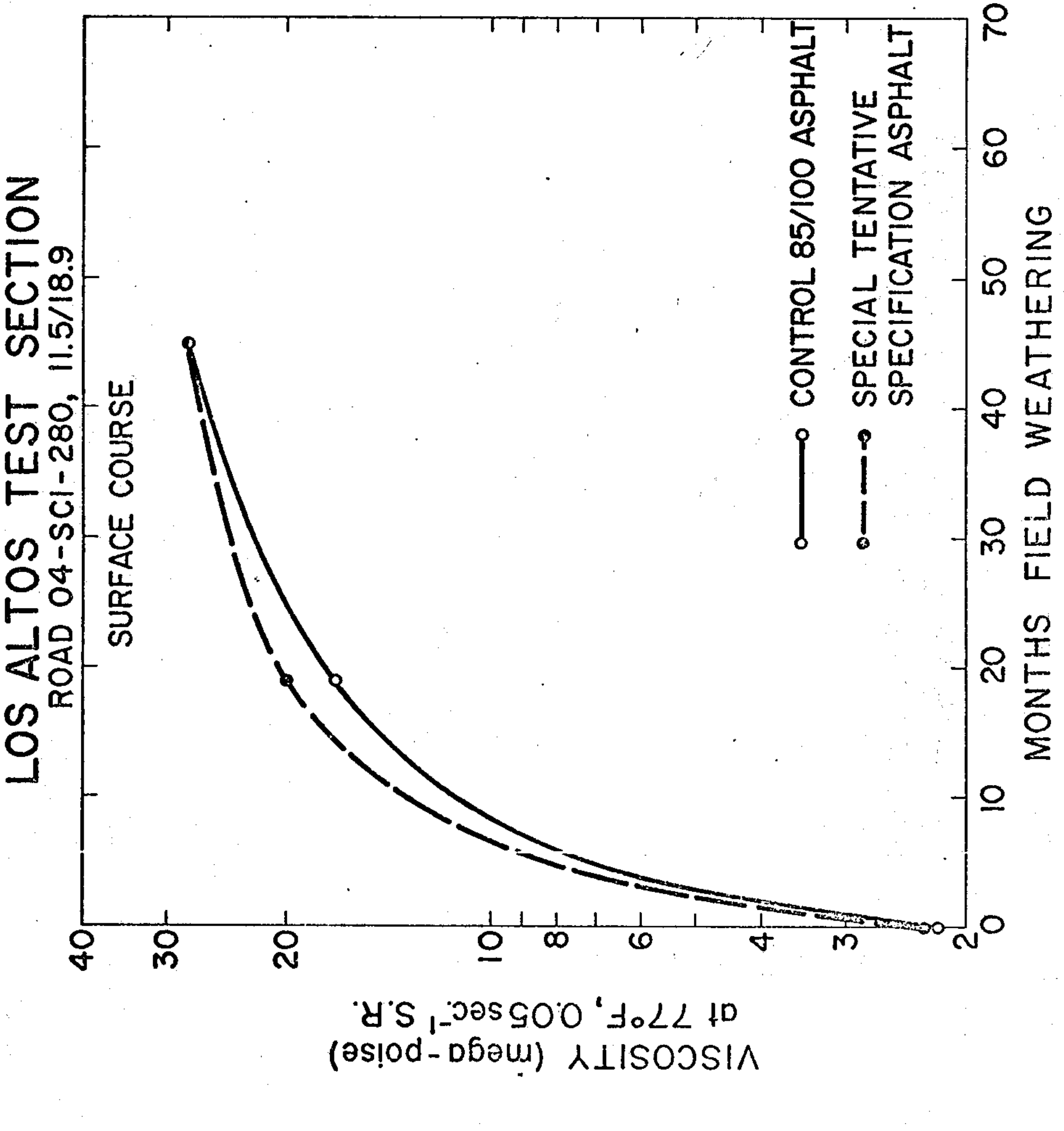

MARTINEZ TEST SECTION
ROAD 04-CC-4, 4.4/9.8 (SURFACE COURSE)
CONTROL 85/100 ASPHALT
SPECIAL TENTATIVE SPECIFICATION ASPHALT
VISCOSITY (mega-poise)
at 77°F, 0.05 sec.⁻¹ S.R.
200
100
50
10
5
3
0
10
20
30
40
50
60
70

Figure 5



LOS ALTOS TEST SECTION
ROAD 04-SCI-280, 11.5/18.9
SURFACE COURSE
CONTROL 85/100 ASPHALT
SPECIAL TENTATIVE SPECIFICATION ASPHALT
VISCOSITY (mega-poise) at 77°F, 0.05 sec.$^{-1}$ S.R.
MONTHS FIELD WEATHERING
40
30
20
10
8
6
4
3
2
0
10
20
30
40
50
60
70

Figure 6

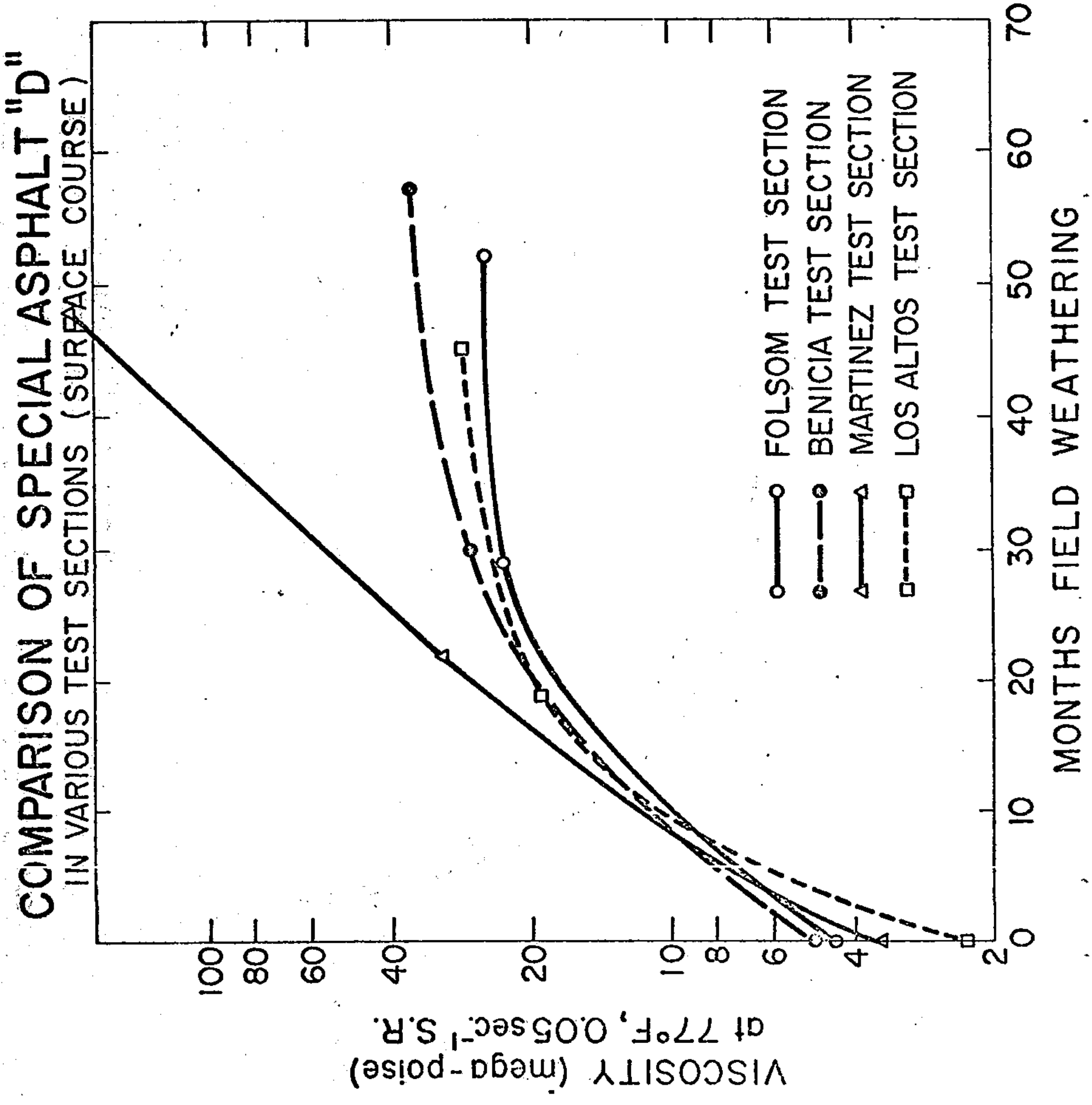

COMPARISON OF SPECIAL ASPHALT "D"
IN VARIOUS TEST SECTIONS (SURFACE COURSE)
FOLSOM TEST SECTION
BENICIA TEST SECTION
MARTINEZ TEST SECTION
LOS ALTOS TEST SECTION
VISCOSITY (mega-poise)
at 77°F, 0.05 sec.⁻¹ S.R.
100
80
60
40
20
10
8
6
4
2
0
10
20
30
40
50
60
70
MONTHS FIELD WEATHERING

Figure 7

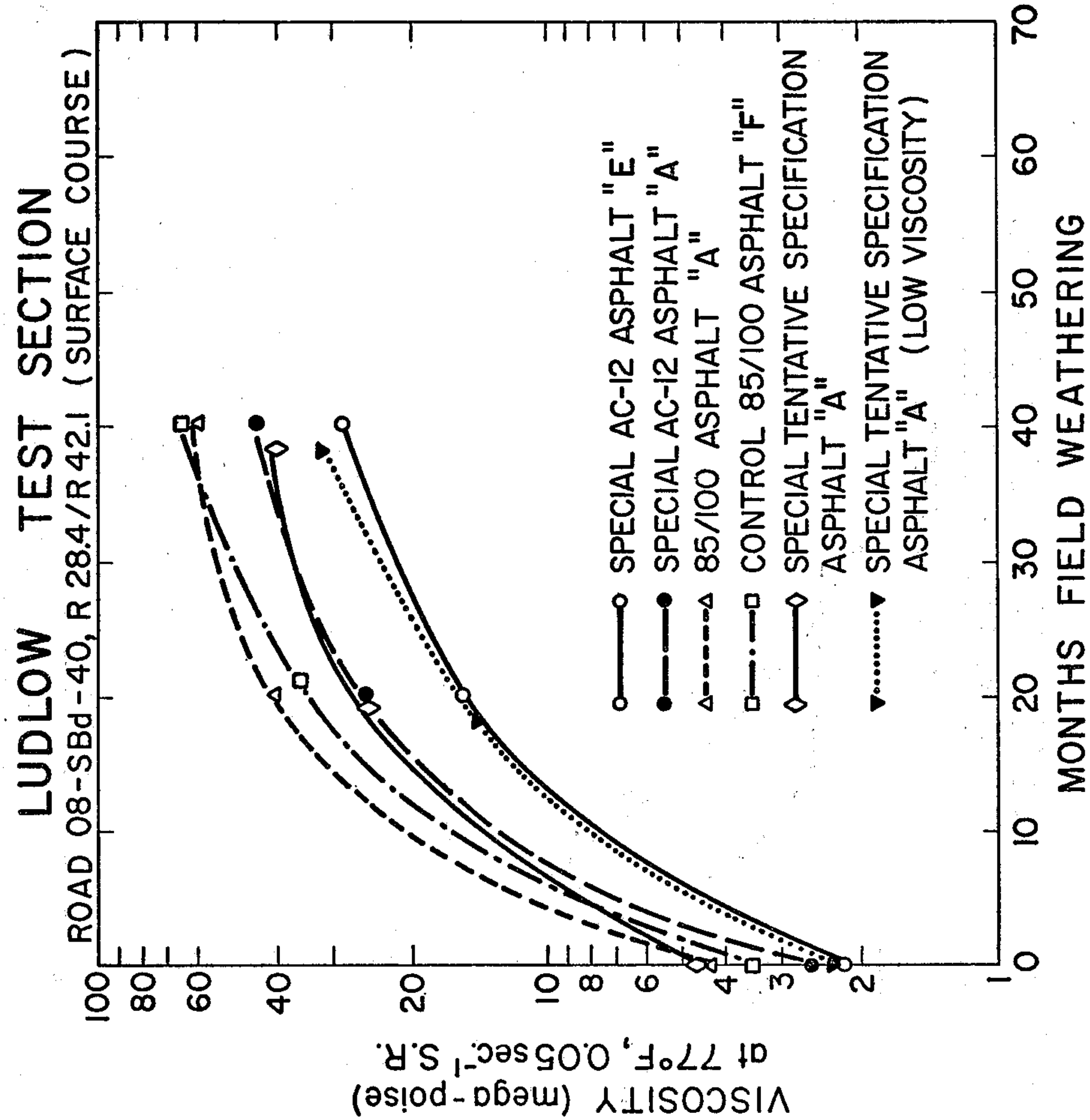

LUDLOW TEST SECTION
ROAD 08-SBd-40, R 28.4/R 42.1 (SURFACE COURSE)
SPECIAL AC-12 ASPHALT "E"
SPECIAL AC-12 ASPHALT "A"
85/100 ASPHALT "A"
CONTROL 85/100 ASPHALT "F"
SPECIAL TENTATIVE SPECIFICATION ASPHALT "A"
SPECIAL TENTATIVE SPECIFICATION ASPHALT "A" (LOW VISCOSITY)
VISCOSITY (mega - poise) at 77°F, 0.05 sec.$^{-1}$ S.R.
100
80
60
40
20
10
8
6
4
3
2
1
0
10
20
30
40
50
60
70
MONTHS FIELD WEATHERING

Figure 8

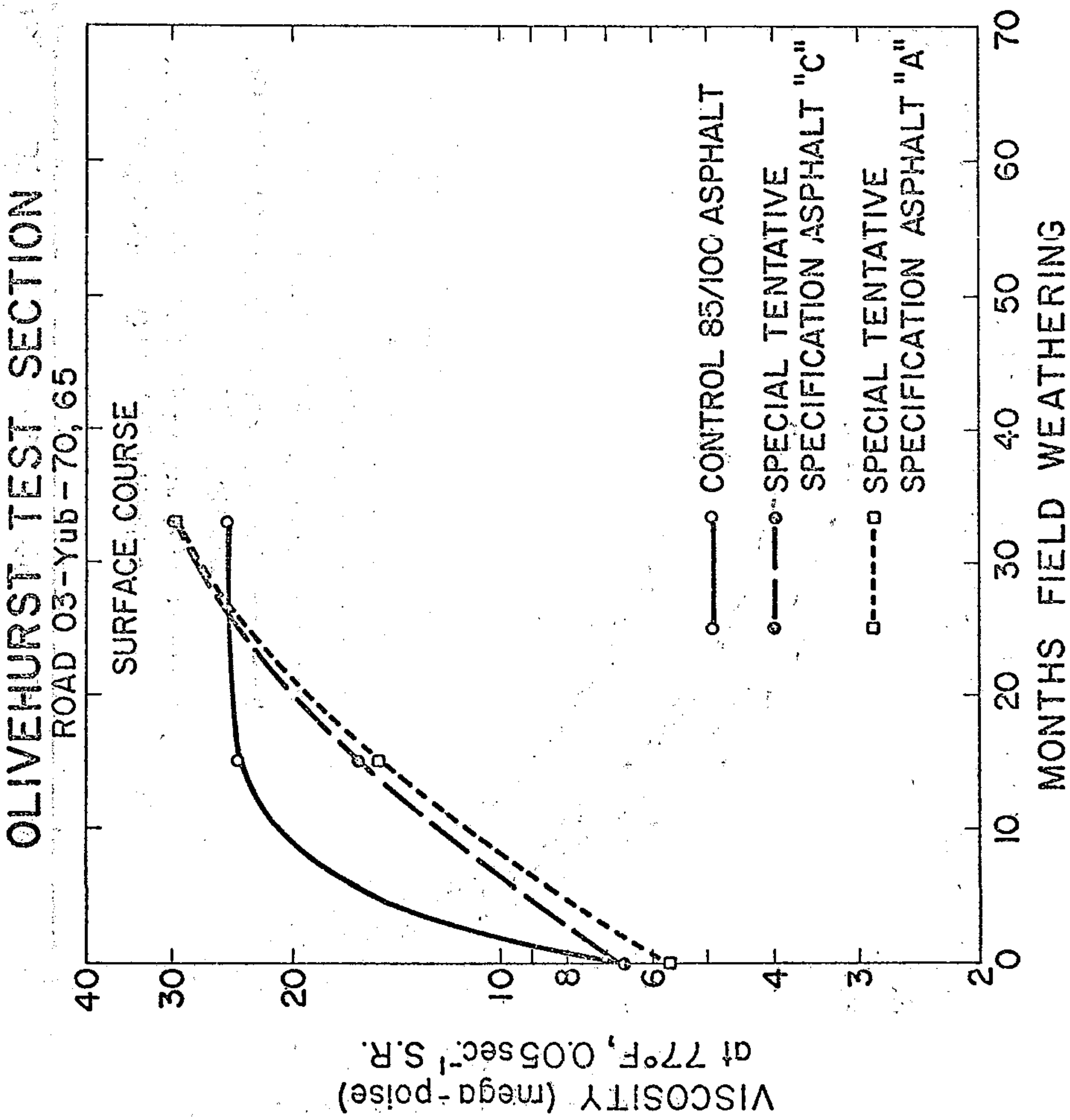
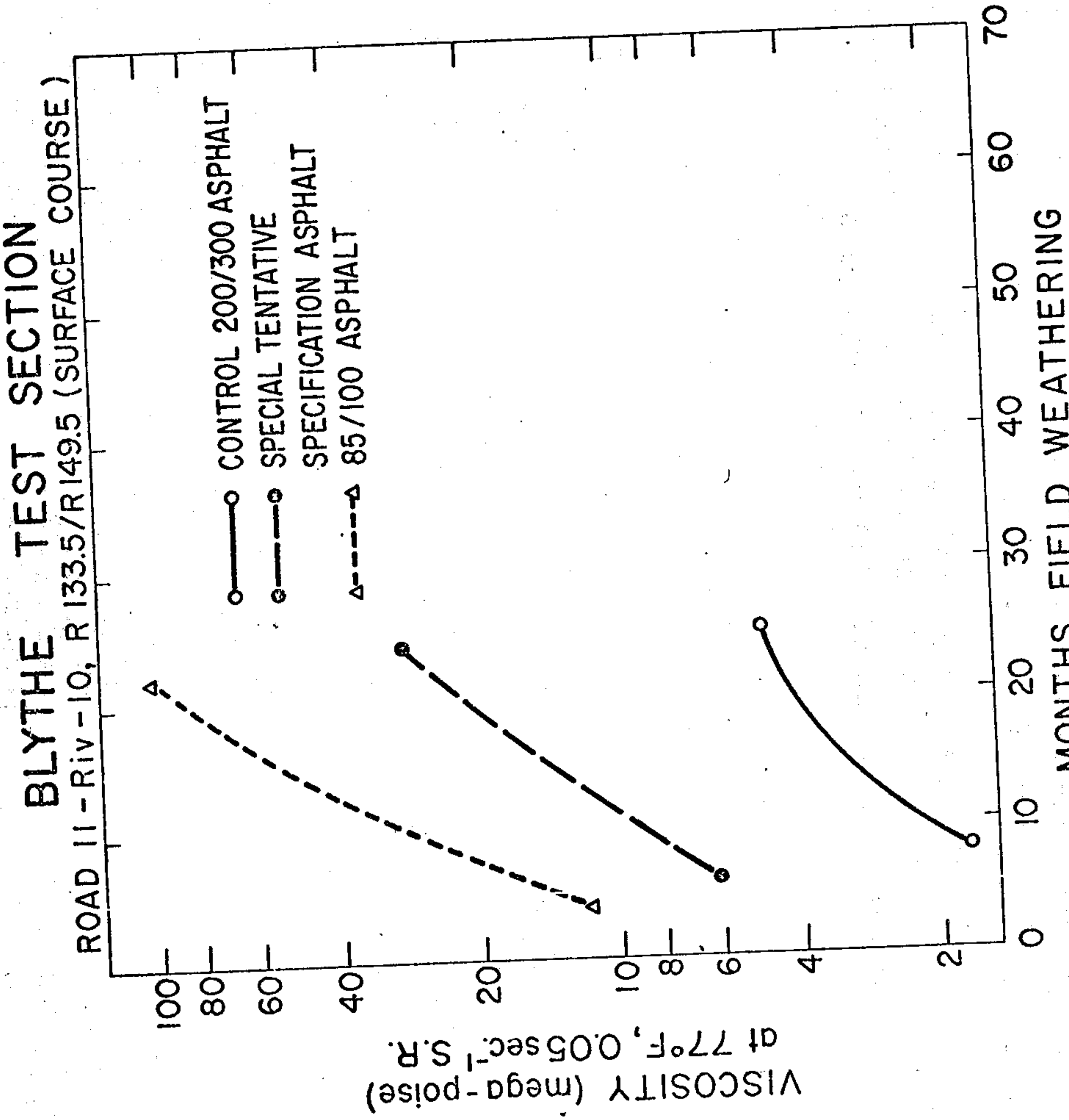

OLIVEHURST TEST SECTION
ROAD 03-Yub-70, 65
SURFACE COURSE
CONTROL 85/100 ASPHALT
SPECIAL TENTATIVE SPECIFICATION ASPHALT "C"
SPECIAL TENTATIVE SPECIFICATION ASPHALT "A"
VISCOSITY (mega-poise) at 77°F, 0.05 sec.$^{-1}$ S.R.
MONTHS FIELD WEATHERING
40
30
20
10
8
6
4
3
2
0
10
20
30
40
50
60
70

Figure 9


BLYTHE TEST SECTION
ROAD 11-Riv-10, R 133.5/R149.5 (SURFACE COURSE)
CONTROL 200/300 ASPHALT
SPECIAL TENTATIVE
SPECIFICATION ASPHALT
85/100 ASPHALT
MONTHS FIELD WEATHERING
0
10
20
30
40
50
60
70
VISCOSITY (mega-poise)
at 77°F, 0.05 sec.⁻¹ S.R.
100
80
60
40
20
10
8
6
4
2

COMPARISON OF CORRELATION COEFFICIENTS
(LEAST SQUARES REGRESSION ANALYSIS = $Y = Ax^b$ & $Y = Ae^{bx}$) OF FIELD WEATHERING DATA AT 30 & 50 MONTHS VARIOUS TEST PROCEDURE'S DATA

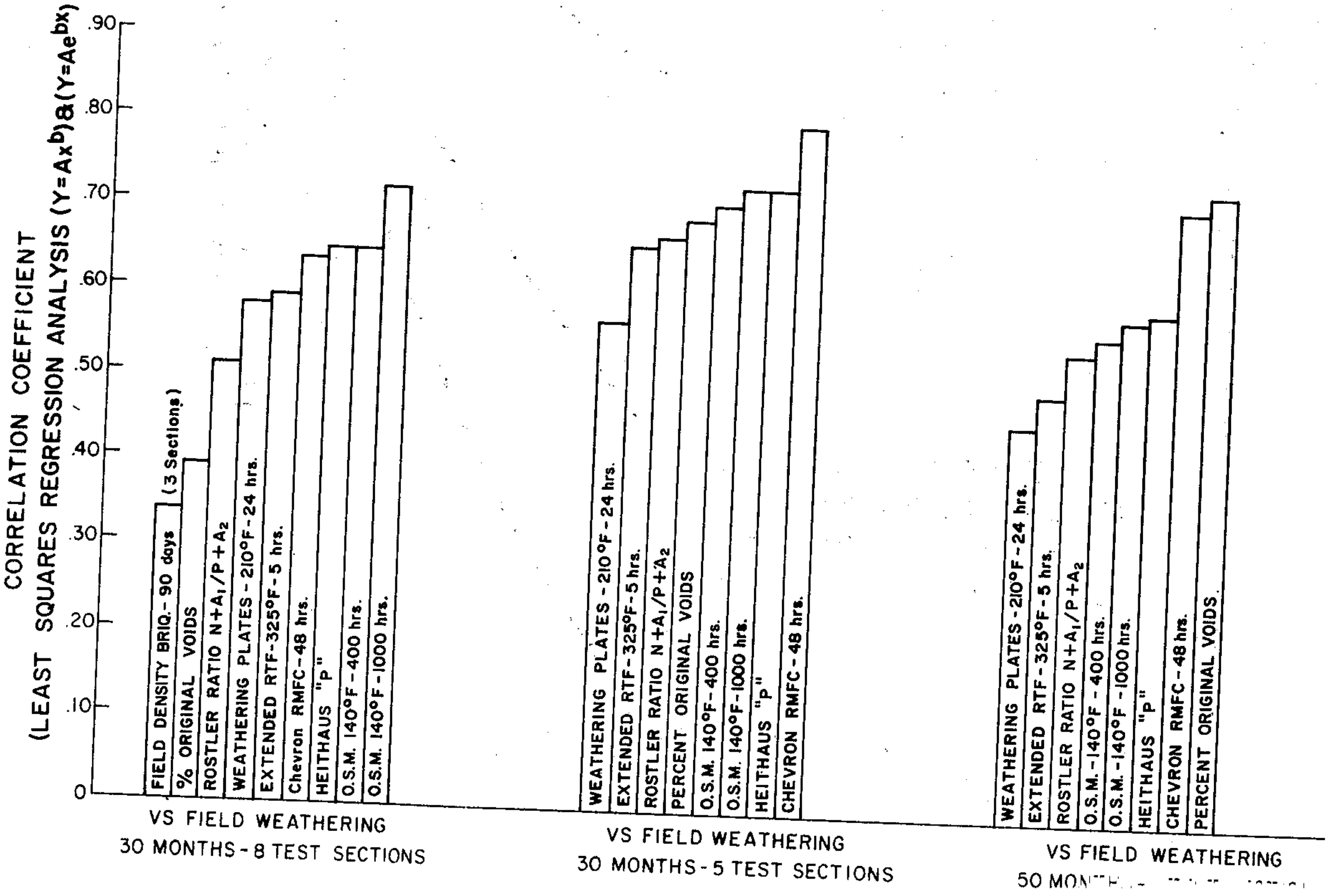


Figure 10

Figure II

COMPARISON OF CORRELATION COEFFICIENTS (LINEAR COVARIANCE ANALYSIS) OF FIELD WEATHERING DATA AT 30 & 50 MONTHS VS VARIOUS TEST PROCEDURE'S DATA

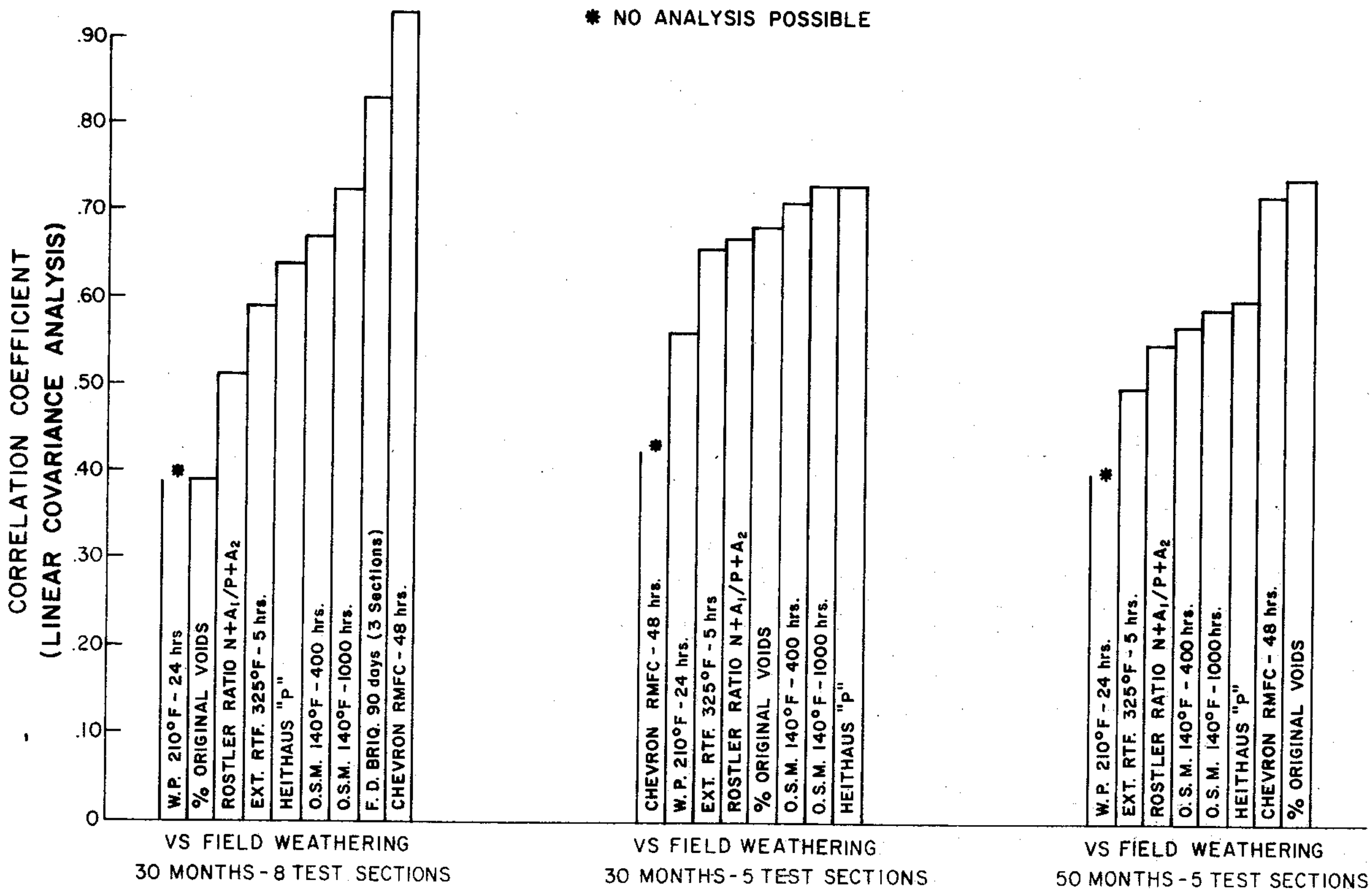


Figure 12

1. Willits Test Section.
2. Folsom Test Section.
3. Benicia Test Section.
4. Martinez Test Section.
5. Los Altos Test Section.
6. Ludlow Test Section.
7. Olivehurst Test Section.
8. Blythe Test Section.